APPENDIX E

GUIDELINES FOR THE EVALUATION OF EXISTING MATERIALS

E-1. Introduction

Many existing buildings may have less strength in members and connections than they would have if they were constructed more recently. This is due to: poor quality control and detailing practices specified at the date of construction; damage or deterioration of structural materials with age or use; and uncertainties in the estimation of the material and section properties. This difference may be taken into account by assigning capacity reduction factors -to members in buildings. These factors should be determined in accordance with the engineers' assessment of the existing conditions of the building under consideration, the confidence level of the estimating material properties, and the workmanship. Physical properties of existing materials are usually available in the original design drawings and construction documents. In the absence of existing data, field investigation and tests of sample members may be required as described in this appendix. The bending moment, shear, and axial load capacities of critical members in existing buildings will be determined assuming that they have the same yield strength as the new materials. Rehabilitation of some existing structural materials to remain in an upgraded building may be required in addition to the modification or strengthening of other materials. Where rehabilitation of damaged or deteriorated structural material is not feasible or cost effective, capacity reduction factors, as described above, may be assigned to the existing members if the member is capable of resisting loads, but at reduced capacity (e.g., a steel beam that has suffered a measurable loss of section due to corrosion).

E-2. Physical properties of existing building materials

a. Structural steel. Physical properties of steel members and connections can be determined with reasonable confidence from the review of existing data and/or field inspection. If the age of the building is known, the physical properties of the steel members may be inferred by reference to manuals or specifications of that time period.

b. Concrete.

(1) *Reinforced concrete.* With reinforced concrete elements, it is essential to estimate the compressive stress (f_c) of concrete and the minimum yield stress (f_y) of reinforcing steel. In addition, the amount of reinforcement and connection details are important factors in evaluating the capacity of reinforced concrete members. Field tests described in paragraph E-3 may be required to verify the existing data available from the as-built drawings and construction documents.

(2) *Unreinforced concrete.* Although unreinforced concrete construction is permitted only in the design of pedestal or footing not on piles, in accordance with recent building codes, most unreinforced concrete components used as structural or nonstructural elements in older buildings have some structural capacity that should be considered in the capacity evaluation. The capacity criteria of unreinforced concrete elements in existing buildings may be determined considering $5\sqrt{f'_c}$ for flexural tension and $2\sqrt{f'_c}$ for shear. Capacity reduction factors should be assigned to account for uncertainties in material evaluation and workmanship of the construction.

c. Masonry.

(1) *Reinforced masonry.* The capacity evaluation of reinforced and unreinforced masonry elements in existing buildings is rather difficult. Because age and deterioration may affect the capacity of existing masonry elements; the type of masonry and the quality of mortar are generally unknown; construction details may be greatly different from current practices; testing is expensive; and interpretation of the test results may be difficult. Despite the above deficiencies, field and laboratory tests of sample members prescribed in paragraph E-3 are advisable. However, in some cases, it may be less expensive to assume a minimum compressive strength (f'_m) consistent with the codes and construction practices at the date of construction rather than to perform extensive field and/or load tests.

(2) *Unreinforced masonry.* Unreinforced masonry construction is generally not permitted in design to resist seismic forces, in accordance with current building codes. However, most unreinforced masonry elements used either as nonstructural partitions or structural elements in existing buildings have some structural capacity and should be considered in the capacity evaluation of existing buildings. The yield strength criteria of existing unreinforced elements may be assumed 1.7 times working stresses specified in agency manuals for ordinary or nonseismic construction. Capacity reduction factors may be assigned to take into

account uncertainties in material evaluation and workmanship of the construction.

d. Timber. The physical properties of wood members and connections may be determined from field inspection and existing data shown in the original design and construction documents. When grade marks are available, appropriate physical properties may be determined by referring to recommended design values by the National Design Specification for Wood Construction or other relevant documents. Conversely, when grade marks are not available but such information is essential, field inspection and/or tests should be performed to evaluate the quality of the materials and their strength properties. However, in some cases, finishes or members must be removed for the field inspection. The decision to undertake extensive explorations involving the removal of finishes should be made by weighing the benefits gained against the costs of such exploration.

e. Foundations. Evaluation of the capacity of existing foundations requires the evaluation of the structural materials (i.e., concrete, piles, drilled piers, etc.) as well as the soil properties. Consultation by a qualified soils engineer and field investigations, including borings and soil tests, may be required to establish appropriate soil properties for the structural performance levels prescribed in this manual.

E-3. Testing criteria for existing materials

Determination of the physical properties of material may be made by in-place, nondestructive testing (NDT), removal of samples for destructive testing, or a combination of both. These two test procedures are described in this paragraph.

a. Nondestructive tests (NDT). The NDT approach has been used for many years for metallic and homogeneous materials. Because the direct determination of strength implies that a sample element must be loaded to failure, it becomes clear that the NDT methods cannot be expected to yield absolute values of strength and are limited in accuracy. The NDT methods for nonmetallic construction materials usually attempt to measure some other property of the material from which an estimate of its strength, its durability, and its elastic parameters are obtained. Some of the NDT methods described below are not truly "nondestructive." They are considered to be relatively nondestructive, in that they generally leave only minor surface damages that can be repaired. On the other hand, coring or cutting is usually considered to be a destructive test.

(1) *Surface hardness tests.*

(a) These tests are an indentation type and consist essentially of impacting the surface of concrete in a standard manner, using a given mass activated by a given energy level, and measuring the size of indentation. The three known methods employing the indentation principle are: Williams testing pistol, Frank spring hammer, and Einbeck pendulum hammer. The test methods are used only for estimating concrete strength.

(b) In-place Brinnel and Rockwell hardness testers are commonly used in the field to estimate the tensile strength and to establish the grade of structural steel or reinforcing steel. These two test methods are standardized in ASTM E 10 and ASTM E 18, respectively.

(2) *Rebound tests.* The Schmidt rebound hammer measures the elastic rebound of concrete and is primarily used for estimation of concrete strength and comparative investigation. The method provides an inexpensive, simple, and quick method for nondestructive testing of concrete, but has serious limitations. It should not be regarded as a substitute for standard compression tests, but as a method for determining the uniformity of concrete in structure and comparing one concrete against another. The Schmidt rebound hammer tests are standardized in ASTM C 805.

(3) *Penetration techniques.* These techniques include the use of the Simbi hammer, Spit pins, and the Windsor probe. They measure the penetration of concrete and are used for strength estimations and for determining the relative strength of concrete in the same structure. Like other hardness testers, these methods should not be expected to yield absolute values of strength of concrete in a structure. The Windsor probe system is standardized in ASTM C 803.

(4) *Ultrasonic pulse velocity method.* This method is used to evaluate uniformity of metallic or nonmetallic material and to estimate its strength and elastic properties. This method involves measurement of time of travel of electronically generated mechanical pulses through a medium, the time interval being measured by a digital meter and/or a cathode-ray oscilloscope. This method has gained considerable acceptance in quality control operations. It has become a common method on construction sites when structural steel welding is involved. The tests can be carried out on both laboratory-sized test specimens and complete structures. The pulse velocity method is standardized in ASTM C 597.

(5) *Radioactive methods.* These methods include the X-ray and gamma ray penetration tests for the determination of rebar and strand location and size, voids in concrete and masonry walls, location of anchors in stone masonry, as well as the detection of weld flaws. The principle of these methods is to place the radiation source on one side

of the member to be inspected and the film on the other. The X-rays or gamma rays penetrate the member, but undergo attenuation in the process. The degree of attenuation depends on the kind of matter traversed, its thickness, and the wavelength (or energy) of the radiation. The maximum member thickness is limited to about two feet. The high initial cost and the immobility of testing equipment in the field, in the case of X-rays, have been the main limitations of these methods. The use of gamma rays has been more acceptable in construction testing because sources such as cobalt and iridium are more portable than X-ray equipment and are easier to use on in situ materials. Tu utilize these methods, both sides of a member must be accessible and very strict safety measures must be taken, as the radiation can be lethal.

(6) *Magnetic methods.*

(a) The Pachometer and cover meters are magnetic devices that can measure the depth of reinforcement cover in concrete and detect the position of reinforcement bars. The methods are based on the principle that the presence of steel affects the field of an electromagnet. The devices give satisfactory results if structural members are lightly reinforced. In heavily reinforced sections, the effect of secondary reinforcement may influence the dial reading, and the satisfactory determination of the cover to steel is practically impossible.

(b) The magnetic particle method is used primarily to locate surface cracks and to detect discontinuities of weld joints on or close to metal surfaces. In this method, an intense magnetic field is set up and magnetic particles are applied to the surface of a section under consideration. Particles will collect at lines of defects. Various colors of magnetic particles are available and can be selected on the basis of contrast with the material surface.

(7) *Nuclear methods.* The techniques include the neutron-scattering method for moisture-content determination and the neutron-activation method for cement-content determination. These methods are not suitable for determining the strength properties of concrete. The application of nuclear methods is still in the experimental stage. The equipment required is relatively sophisticated and expensive.

(8) *Electrical methods.* The application of electrical methods has been along the lines of: determination of moisture content of concrete by dielectric measurements, tracing of moisture permeation through concrete by electrical resistivity probes, and determination of thickness of concrete payments by electrical resistivity measurements. Because the development of electrical methods for concrete is limited to specialized applications only, these methods have received very limited acceptance by the concrete industry.

(9) *Microwave absorption techniques.* These techniques have been used to estimate the moisture content and thickness of concrete. Because of the electromagnetic nature of the microwaves, they can be reflected, diffracted, and absorbed. The absorption of these waves by water has led to the development of a method of determining the moisture content of concrete and brick. These techniques are still in the development stage and are not ready for much practical application.

(10) *Acoustic emission techniques.* These techniques have been used to study the initiation and growth of cracks in metals and concrete, but they are still in their infancy.

(11) *Load tests.* The gravity load testing of a structure or a segment is used to establish the factor of safety with respect to the simulated dead and live loads. Floor or roof flexural members are the most frequently tested. However, vertical elements can also be tested with similar techniques. American Concrete Institute Building Code Requirements (ACI 318-83), Chapter 20, and the Uniform Building Code (UBC), Section 2620, prescribe criteria for the acceptance of a test component. The applied load is specified as 85 percent of the sum of 1.4 times the dead load plus 1.7 times the live load. If the maximum deflection of a beam, floor, or roof exceeds the square of the span divided by the product of the member thickness and 20,000, the deflection recovery within 24 hours after the removal of the test load must be at least 75 percent of the maximum deflection. If the measured maximum deflection is less than this value, no deflection recovery requirements are imposed. The load tests are considered to be the most expedient method of establishing the safety of a structure with respect to gravity loading. With the exception of individual frames, it is generally not practical to load test for lateral forces.

(12) *Dynamic response testing.* The technique of artificially exciting a structure to determine its dynamic response characteristics is occasionally performed. The test results are useful to verify the adequacy and reliability of structural models developed during the analytical phase of building rehabilitation. Measurements of accelerations, displacements, and strains are often required. The structure can be excited by vibration generators or a low-amplitude pull-and-release technique.

(13) *Strain measurements.* Load, strain, and displacement measurements are commonly used in connection with static and dynamic load tests to

monitor the response of a structure. Electrical resistance strain gauges bonded to members at strategic locations are used to monitor changes in electrical resistance. Displacement and force measurements may be done remotely by electronic devices or by direct measurements such as dynamometers, potentiometers, or others.

b. Testing criteria of sample materials. Visual field inspection is probably the most important and least expensive method of quality assurance, but it is limited to surface evaluation. Other methods of nondestructive and destructive testing must be supplemented with visual inspection for full quality assurance. Sample materials should be selected objectively, so that sample elements are not weighted to be nonrepresentative. Furthermore, sample locations should be spread randomly or systematically over the structure in question. This paragraph prescribes the criteria for destructive testing of sample materials and summarizes some of the nondestructive testing methods described above which are commonly employed in field and laboratory tests for certain construction materials.

(1) *Structural steel.*

(a) Destructive testing. Material used in older buildings may no longer be in current use and, therefore, must be identified by reference to ASTM designations and specifications which were in effect at the time of construction. In the absence of existing data, the destructive testing of sample materials cut from sections of a structure should be made, along with nondestructive tests described below. The laboratory testing of tensile strength and other pertinent material properties should be performed in accordance with ASTM A 370. In taking sample elements, special care must be taken to not reduce the load-carrying capacity of the structure. When material is removed at critical sections, temporary supporting may be needed.

(b) Nondestructive testing.

1. Verification of dimensions. Visual measurement, size, thickness, and material uniformity, including possible corrosion, can be accurately and quickly determined by the ultrasonic pulse velocity method (ASTM C 597).

2. Determination of in-place tensile strength. In-place Rockwell (ASTM E 18) and Brinnell (ASTM E 10) hardness testers can be used to estimate the tensile strength and to establish the grade of steel.

3. Inspection of welds. The nondestructive testing of welds and weld-related material plays a very important part in quality assurance. In addition to visually determining size and apparent quality, nondestructive methods for flaw detection, such as the ultrasonic pulse velocity method, the radioactive method, the magnetic particle method, and the liquid penetrant method. The use of penetrants is especially useful in the detection of tight surface cracks which might not be detected easily by visual examination.

(c) Load tests and dynamic response measurements. Load tests may be used to establish the safety of a structure with respect to gravity load. Dynamic response measurements may be desirable when doubt arises concerning the adequacy and reliability of mathematical models developed during the analytical phase of building rehabilitation.

(2) *Reinforced concrete.*

(a) Destructive testing. Cores provide the best qualitative method for determining compressive strength, unit weight of concrete, Poison's ratio, and modulus of elasticity of existing structures, which are essential for determining structural capacity of existing elements. A standard size of core is 6 in. by 12 in. (diameter by height); however, a 4-in.-diameter core may be acceptable. The ideal core will have a height-to-diameter ratio of 2.0, but not less than 1.0. In taking cores and in exposing and removing steel reinforcement, special care must be taken to not reduce the load-carrying capacity of the structure. Samples should be representative, and they should be done in a way to avoid rebars. The number of cores depends on the purpose of coring and the size of the structure. A minimum of three cores is recommended. The testing criteria have been standardized in ASTM C 42. The destructive core testing should be performed along with one or more of the nondestructive tests below.

(b) Nondestructive testing.

1. Uniformity of concrete. The Windsor probe system (ASTM C 803), the Schmidt hammer (ASTM C 805), and the ultrasonic pulse velocity method (ASTM C 597) can be used to determine the uniformity of field concrete.

2. Crack detection. Crack depth, size, direction, and propagation can usually be determined with the pulse velocity equipment (ASTM C 597).

3. Location and size of reinforcing bars. The Pachometer can be used to locate reinforcing steel, size, and depth of cover.

4. Strength of reinforcing bars. The chipping gun can be used to expose reinforcing steel. Access will provide the opportunity to establish the grade visually. However, an in-place Rockwell ASTM E 18 or Brinnell ASTM E 10 tester can be used to establish the grade of reinforcing steel if it cannot be determined visually. Alternatively, a laboratory tensile test (ASTM A 37) may be performed if more accurate tensile strength is desired.

(c) Load tests and dynamic response mea-

surements. Load tests prescribed in ACT 318-83, Chapter 20, and UBC, Section 2620, may be used to determine the safety of a structure with respect to the gravity loading. Dynamic response measurements may be useful in the development of realistic analytical models for seismic safety evaluation.

(3) *Masonry.*

(a) Destructive testing. The traditional method of determining shear strength of mortar is to cut an 8-in, core and test the core in the laboratory with the bed joint rotated to a position 15 degrees off vertical. Disadvantages are: the coring machine is cumbersome, water is required in cutting and is difficult to control, the sample is often damaged during cutting, and the resulting hole is difficult and expensive to repair. An alternate method is the in-place push test developed in conjunction with Division 68-Earthquake Hazard Reduction in Existing Buildings for the City of Los Angeles. In this method, a brick adjacent to the test brick is removed by drilling or sawing out the mortar joint. The head joint on the opposite end is also removed. A calibrated ram is placed in the space left by the removed brick and a load is applied until the test brick's bond is broken. This test is simple to perform and is nondestructive. It is easy to repair and relatively inexpensive. This test has the advantage of retaining the actual vertical load on the test brick, a condition that is difficult to achieve in laboratory testing. The tests are usually conducted at various heights to vary the actual dead load condition and at horizontal locations to minimize concentrations of load. The desirable frequency of tests is one test sample per 1,500 ft^2 of wall area with a minimum of two tests per wall. The following structural properties of masonry walls are usually of interest to the engineer in evaluating the structural capacities of masonry elements.

f'_m = compressive strength

f_v = shear strength under diagonal compression, ASTM E 447

f_t = tensile strength under out-of-place flexure and lateral loading, ASTM E 519

G = modulus of rigidity

The ASTM tests cited above are written for field-constructed test samples rather than drilled or sawn samples; however, the same criteria can be used with a few slight modifications.

Guidelines for selection of sample specimen may be consulted in the National Bureau of Standards study for the Veterans Administration titled "Evaluation of Strength of Existing Masonry Walls."

(b) Nondestructive testing.

1. Location and size of rebars. The radioactive methods (X-ray or gamma ray) are often used to determine the location and direction of rebars, depth below surface, and size of reinforcement when both sides of a wall are accessible. The Pachometer can also be used for the same purpose when one or both sides are exposed.

2. Uniformity of masonry. Voids and rock pocket areas of a double-wythe brick wall with a grout or concrete infill can be detected by the ultrasonic pulse velocity method.

(c) Load tests and dynamic response measurement. Load tests may be used to determine the safety of-an element or a structure to resist the gravity design loads.

E-4. Rehabilitation of existing structural materials

Rehabilitation of existing damaged or deteriorated structural materials may be a significant factor in the seismic upgrading of some existing buildings, incidental to, or in addition to structural modifications and strengthening procedures. Following are representative examples of feasible rehabilitation for various structural members:

a. Structural steel. Moderate accidental damage, such as bent flanges, may be repaired by flame straightening and/or jacking or peening. Care must be taken to shore loaded steel members prior to heating. Corroded or otherwise deteriorated removable elements of steel framing, such as bolted bracing and fasteners, may be replaced with new elements. Scale and other corrosion byproducts shall be removed and the steel members lightly sandblasted in preparation for a rust preventative undercoat and painting. The loss of effective section can be evaluated after sandblasting and the assigned capacity reduction factor will be re-evaluated.

b. Reinforced concrete. Prior to undertaking the rehabilitation of existing concrete structures, the apparent cause of the damage must be ascertained.

(1) If cracking or other signs of distress can be related to differential settlement due to consolidation of the soil under the footings, soil investigations will be necessary to determine anticipated future consolidation and the cost effectiveness of rehabilitation.

(2) If the cracking is related to the shrinkage and heaving of expansive soils under the foundations, rehabilitation may be cost effective if supplementary measures are taken to restrict excessive changes in the moisture content of the soil. These measures may include removal of foundation planting and paving a strip to exclude moisture from the soil around the perimeter of the building.

For buildings with exposed soil in crawl spaces under the first floor, a moisture barrier with a sand or concrete cover may also be required.

(3) Cracks in concrete walls may also be due to initial drying shrinkage of the concrete or to temperature expansion and contraction. Hairline cracks are normal in concrete structures and have little or no detrimental effect on its strength. Evidence of rust stains at a concrete crack may indicate that moisture is intruding and corroding the reinforcement. If this is not corrected, the corrosion will progress and eventually spall the concrete surface. When this condition exists, the crack should be routed out to expose the reinforcement which should be thoroughly cleaned by wire-brushing prior to patching the crack with an epoxy mortar. Although it may not be possible to prevent the cracking due to temperature expansion and contraction, control joints are effective in limiting the location of these cracks. Vertical control joints can be sawed in the outside face of concrete walls at about 8 foot centers to a depth of about ¾-inch. The sawed joint is then filled with an elastomeric sealer to exclude water. Epoxy injection is an effective method for sealing concrete cracks and restoring shear strength. Epoxy injection requires special equipment and procedures and is best accomplished by an experienced specialty contractor.

(4) Spalling of concrete surfaces in cold climates is usually caused by the freezing and expansion of water intruding into the pore spaces of the concrete. This may be prevented by a suitable elastomeric coating to exclude the moisture.

c. Masonry. The various causative factors contributing to the cracking of concrete walls, and the mitigation of those factors, described in the preceding paragraph, also apply to masonry walls. The weakest element in older masonry is usually the mortar joint, particularly where significant amounts of lime was included in the mortar and subsequently leached out by exposure to the weather. For this reason, cracks in masonry walls will usually occur in the joints, although occasionally well-bonded masonry will crack through the masonry unit. Epoxy injection is the recommended procedure for sealing cracks and restoring shear strength for masonry walls with cracks in the joints or through solid masonry units. Where cracks occur through hollow masonry units, it may be feasible to pump mortar in the cracked units to restore shear strength prior to epoxy injection of the face shells. A common problem in masonry walls is the intrusion of moisture to the inside of the building through the joints where the mortar has cracked or where the drying shrinkage of the mortar or the units has formed a path for moisture to penetrate the wall. This condition can be remedied by routing out the mortar joints in the exterior face of the wall to a depth of about ½-inch and sealing the joint with an elastomeric joint sealer.

d. Timber. Common problems, requiring rehabilitation of timber structures, include termite attack, fungus ("dry rot" or "damp rot"), and warping, splitting or checking due to shrinkage or other causes.

(1) *Insect damage.* The subterraneous termites are the most common termite variety in the United States. These insects live in the ground and construct soil tubes to the timber members that they infest. These termites can be controlled by fumigants and toxic saturation of the soil. Preventative measures include concrete curbs or pedestals (at least 12 inches high) to remove the timber from close proximity to the ground. Sheet metal shields at the top of the concrete and the use of wood preservation for timber bearing on the concrete curb or pedestal are also common preventative measures. Dry wood termites and wood boring insects can also be controlled by fumigation and by painting of the exposed timbers with a suitable penetrating chemical preservative. Damaged portions of the timber structural members will be removed and replaced or supplemented with additional members if the infestation has been properly controlled.

(2) *Fungus.* Fungus damage to timber in buildings usually occurs where the timber is allowed to be saturated for long periods of time. Wood preservative is a good preventative measure, but in the presence of excess moisture, it will be leached out and become ineffective. The optimum solution is to exclude the moisture from the inside of the building (e.g., attic spaces with leaky roofs, crawl spaces with water leaks, etc.); provide good ventilation to the affected areas; and use wood preservative for timber members in contact with exterior masonry or concrete walls. Damaged structural members will be removed, replaced, or supplemented as described above for insect damage.

(3) *Warping, splitting, or checking.* These are common problems with older timber structures. If the distress can be attributed to the presence of excessive knots, or drying shrinkage of the wood, the timber members will be removed and replaced or supplemented with additional members to resist the applied loads. If, however, the distress is due to overstress, differential settlement, or improper connection details, then these conditions must be corrected before the individual members are repaired or replaced.